Laboratory Measurements of Multi-Frequency and Broadband Acoustic Scattering from Turbulent and Double-Diffusive Microstructure

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LONG-TERM GOALS

The long-term goal of the proposed research is to develop a fundamental understanding of high-frequency acoustic scattering from small-scale physical processes that occur in the ocean interior.

OBJECTIVES

The primary scientific objective of the proposed research is to measure, characterize, and understand, the physics of high-frequency acoustic scattering from tank-generated microstructure, including turbulent microstructure and double-diffusive phenomena such as salt-fingers and sharp double-diffusive interfaces, at both forward and backscattering geometries. In addition to laboratory measurements, objectives for this research also include:

- The initial development of realistic microstructure scattering models and the methodology for interpreting high-frequency acoustic sonar survey data.
- Understanding microstructure-induced phase variability, particularly in the forward scattering direction.
- Assessing the feasibility of using high-frequency acoustic scattering techniques to determine temperature and salinity wave-number spectra, particularly the high wave number region of the salinity spectrum, as well as the, still unmeasured, temperature-salinity co-spectrum.

APPROACH

Oceanic microstructure refers to a variety of small-scale physical processes that give rise to large gradients in temperature and salinity, and thus in oceanic density and sound speed. These fluctuations in the medium material properties result in the scattering of high-frequency sound. There is evidence suggesting that oceanic microstructure can be a significant source of high-frequency acoustic scattering, as significant as that from other naturally occurring sources. The approach taken here to understanding acoustic scattering from different types of microstructure involves a combination of laboratory experiments and theoretical model development. Controlled laboratory experiments are performed in which the frequency, waveform, range, beam parameters, and physical parameters governing the microstructure are known or measured. The experiments are principally in the backscatter configuration, although some forward scattering measurements are also made. The acoustic frequencies employed are in the 100-2000 kHz. A combination of broadband and

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The long-term goal of the proposed research is to develop a fundamental understanding of high-frequency acoustic scattering from small-scale physical processes that occur in the ocean interior.

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narrowband transducers are employed together with chirp and/or gated sine wave signals. The data collected will be used to refine existing and guide the development of new acoustic scattering models. All aspects of the research associated to this project are performed by Andone C. Lavery.

WORK COMPLETED

Two major tasks have been completed: 1) construction of the acoustic scattering laboratory for performing measurements of scattering from different types of tank-generated microstructure, and 2) completion of the first set of measurements involving backscattering from double-diffusive interfaces.

1) CONSTRUCTION OF THE ACOUSTIC SCATTERING LABORATORY. The initial goal of the project was to set up an acoustic scattering laboratory to perform measurements of high-frequency acoustic scattering from different types of laboratory generated microstructure. This goal has been achieved and a state-of-the-art high-frequency acoustic scattering laboratory is now fully operational. The measurements are performed in a 4.6-meter tall microstructure tank facility (Fig. 1) at Woods Hole Oceanographic Institution (WHOI). The construction of the laboratory included an optical shadowgraph imaging system, the purchase and installation of high-resolution microstructure probes for direct measurements of temperature and conductivity microstructure, the development of an integrated data acquisition system, and the construction of forward and backscattering acoustic arrays. The laboratory hardware was purchased, and the data acquisition software and interfacing were completed by the end of February 2003. All acoustic and microstructure measurements are digitally recorded by means of an integrated National Instruments data acquisition system. A multi-channel high-speed (10M Samples/s) simultaneously sampling PXI DAQ module made it possible to synchronously sample four input acoustic signals. This is critical when looking at phase differences between signals. Construction of the acoustic backscattering array was completed during the early weeks of 2003 (Fig. 2). The array is sturdy yet flexible, allowing reproducible backscattering measurements to be performed. A second array was also constructed for forward scattering and calibration measurements. The optical shadowgraph system, consisting of a bright monochromatic light source, lens system, 45^o mirror, and digital camera, was set up to visually observe the different types of microstructure coincidentally with the acoustic scattering measurements. Fast temperature and conductivity probes were purchased, installed, and tested, by early March 2003. Testing, evaluation, and calibration of the equipment was completed by May 2003.

2) MEASUREMENT OF ACOUSTIC SCATTERING FROM DOUBLE-DIFFUSIVE INTERFACES. The first set of experiments involving scattering from the “diffusive convection” form of double diffusion has been completed. For this form of double-diffusion a bottom layer of salty water is heated from below, while a top layer of fresh water is cooled from above. A very sharp interface (order 2 cm thick--Fig. 3) in temperature, salinity, density, sound speed and optical index of refraction develops and can be maintained for weeks at a time. Data have been collected at 120 kHz, 160 kHz, and 200 kHz, at ranges of 30, 50, 75, and 100 centimeters from the interface.

RESULTS

A central scientific goal of this project is to measure and characterize high-frequency acoustic scattering from different types of tank- generated microstructure, and ultimately, to develop acoustic scattering models that accurately describe the scattering. The first stage of this project, the

construction of the acoustic scattering laboratory, has been successfully accomplished. The first set of experiments, involving scattering from a double-diffusive interface, has also been completed. To the best our knowledge this is the first laboratory experiment involving high-frequency scattering from double-diffusive interfaces. It has been found that, for a particular frequency and range, there is significant variability in the magnitude of the acoustic backscattering returns on very short time-scales. This illustrates the complex nature of the scattering processes involved, and the resulting need for a relatively sophisticated scattering model that can reproduce the observed variability. In addition, there is a high correlation between the density ratio, which changed by almost an order of magnitude, and the scattering returns. The interface thickness, once fully developed, remained relatively constant throughout the experiments. The initial steps for developing a model for scattering from double-diffusive interfaces have been taken. In addition, a model for scattering from turbulent microstructure that includes the contribution from density fluctuations has been developed [see publications section below].

IMPACT/APPLICATIONS

The potential impact and applications of the results of this project could be significant. This research could provide significant insight into the effects of scattering from different types of microstructure on signal attenuation and coherence. Gaining a deeper understanding of acoustic phase variability due to scattering from microstructure may also result in the improvement of data transfer rates for high-frequency shallow-water acoustic communication applications. Ultimately, this research may also allow high-frequency scattering techniques to become a useful remote sensing tool to synoptically characterize and map the spatial and temporal distributions of oceanic microstructure.

RELATED PROJECTS

Andone Lavery and Peter Wiebe (Biology Department, WHOI) were recently funded through the WHOI Access to the Sea Award for a project entitled "*High-frequency acoustic volume backscattering: discriminating between oceanic microstructure and zooplankton*". The goal of the project is to discriminate between regions in which volume scattering is dominated by biology versus turbulent microstructure. The approach to be taken involves obtaining almost simultaneous high-resolution microstructure measurements (through the use of the high-resolution vertical microstructure profiler HRP), high-frequency volume backscattering data (through the use of the two-frequency towed instrument Greene Bomber and a six-frequency TAPS system mounted to a CTD rosette), and biological sampling (through the use of a nine-net MOCNESS system). Regions of interest include internal waves propagating onto the New England continental shelf, for which the contribution to scattering from microstructure is expected to be elevated. Advantage will be taken of the scattering models developed here to analyze the data collected during the cruise.

PUBLICATIONS

Lavery, A. C., Schmitt, R. W., and Stanton, T. K. (accepted). "*High-frequency acoustic scattering from turbulent oceanic microstructure: the importance of density fluctuations*," to appear in the November 2003 issue of the Journal of Acoustical Society of America [refereed].

THE MICROSTRUCTURE TANK FACILITY

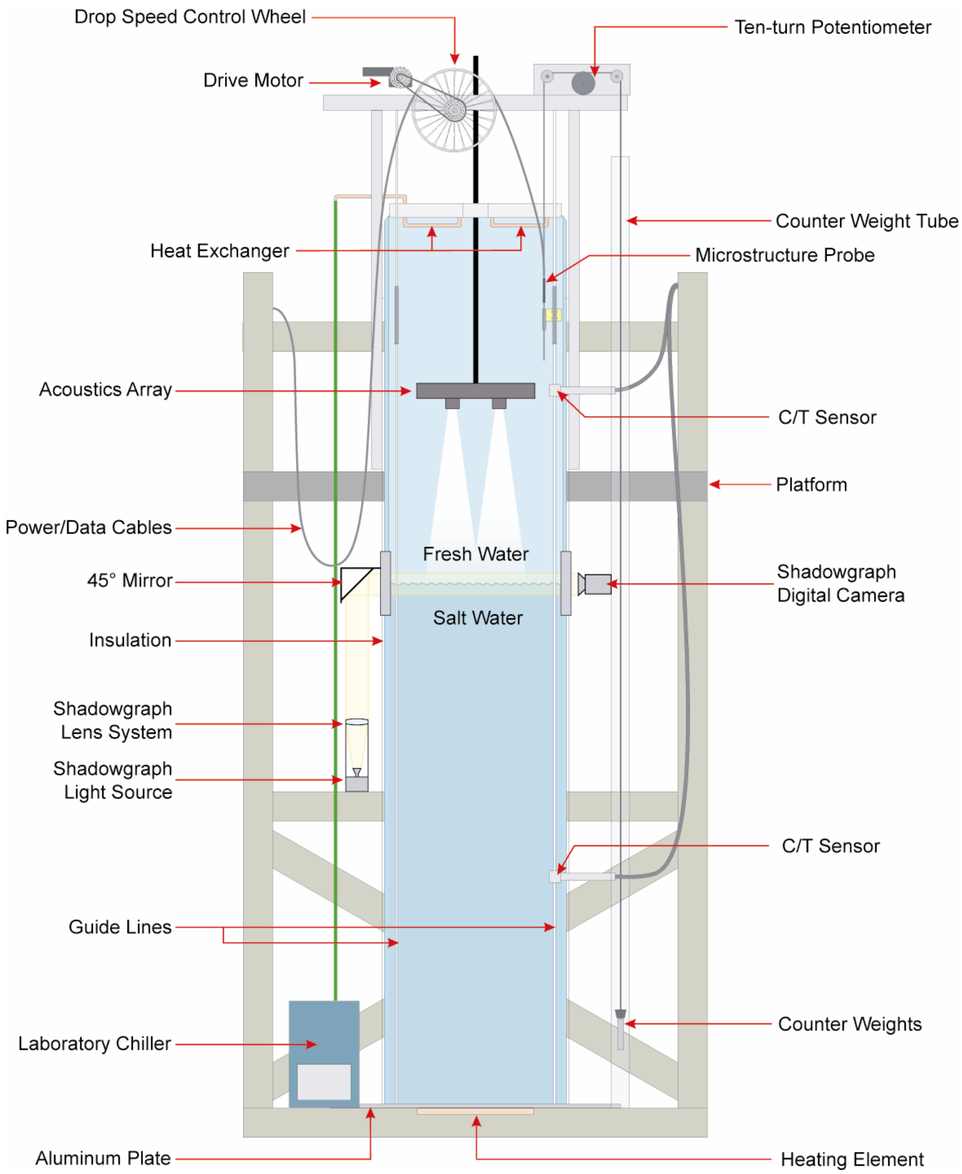

Figure 1. The experimental microstructure tank facility at Woods Hole Oceanographic Institution. The tank is 4.6 m (15 ft) high and 0.91m (3 ft) in diameter. Two opposing mid-depth windows, a bright white light source, focusing lenses, a 45^{o} mirror, and a digital camera constitute the optical shadowgraph system. The high-frequency acoustics backscattering array can be positioned at any depth in the upper two meters of the tank. Temperature and conductivity sensors can be profiled through the tank and two CT sensors provide continuous monitoring of the top and bottom layer properties at two points. For the "diffusive convection" form of double diffusion a bottom layer of salty water is heated from below, while a top layer of fresh water is cooled by cooling coils suspended below insulating foam at the top. By introducing heating and cooling coils at other depths a stable temperature stratification suitable for salt finger or doubly-stable experiments can be obtained. By dropping grids through different temperature and salinity gradients turbulent temperature and salinity microstructure can be generated. By controlling the grid spacing and drop speed different characteristic turbulent length scales can be probed.

MULTI-FREQUENCY ACOUSTIC BACKSCATTERING ARRAY

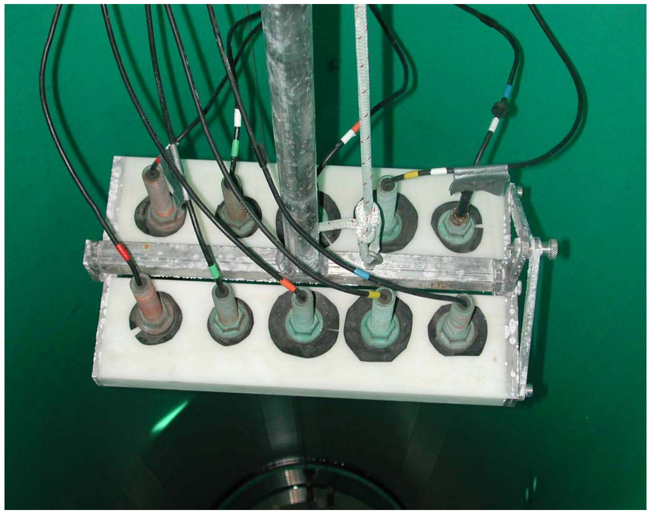

Figure 2. The multi-frequency acoustic backscattering array. The backscattering measurements were performed with one transmit and one receive transducer, placed in a bi-static configuration with the separation between the transducers minimized to simulate a mono-static measurement. The array is sturdy yet flexible, allowing reproducible backscattering measurements to be performed. The acoustics data acquired during these experiments will be used in the future to develop and constrain advanced acoustic scattering models.

TYPICAL SHADOWGRAPH IMAGE OF A DOUBLE-DIFFUSIVE INTERFACE

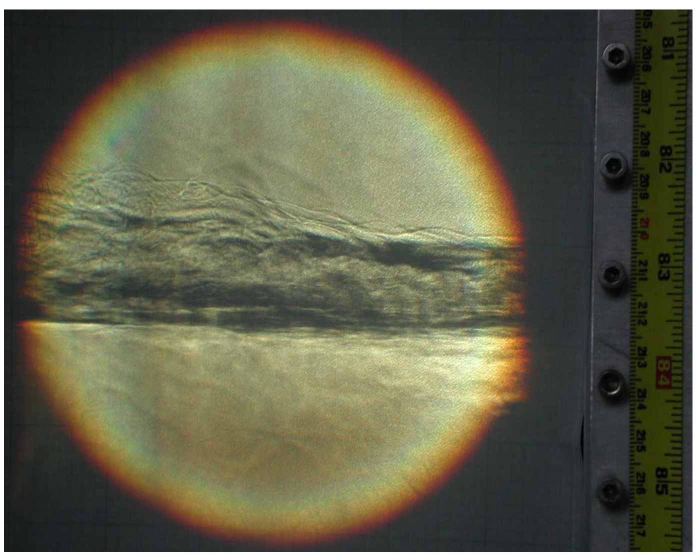

Figure 3. A typical double-diffusive interface optical shadowgraph image. Typical interfaces are 2 centimeters thick (length scale to the right), with temperature gradients of 5 ^oC per cm, salinity gradients of 7 psu per cm, and density ratios spanning the range from 20 to 1.5 (the interface rapidly overturns once the density ratios falls below approximately 1.5).